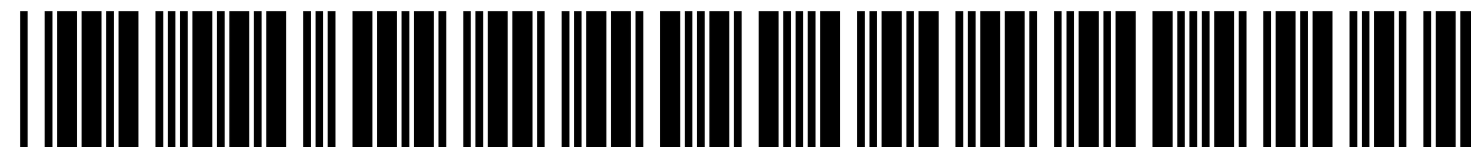

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Akatsuka et al.

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(54) **LIGHT EMITTING APPARATUS AND PROJECTOR**

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(51) **Int. Cl.**

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| ***H01L 33/52*** | (2010.01) |
| ***H01L 33/38*** | (2010.01) |
| ***G03B 21/20*** | (2006.01) |

(52) **U.S. Cl.**
CPC .......... ***H01L 33/04*** (2013.01); ***G03B 21/2033*** (2013.01); ***H01L 33/382*** (2013.01); ***H01L 33/52*** (2013.01)

(58) **Field of Classification Search**
CPC ....... H01L 33/04; H01L 33/382; H01L 33/52; G03B 21/2033
See application file for complete search history.

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(57) **ABSTRACT**

A light emitting apparatus includes an electrode and a laminated structure. The laminated structure includes an n-type first semiconductor layer, a light emitting layer, a p-type second semiconductor layer, a tunnel junction layer, and an n-type third semiconductor layer. The electrode is electrically connected to the first semiconductor layer. The first semiconductor layer, the light emitting layer, the second semiconductor layer, the tunnel junction layer, and the third semiconductor layer are arranged in a presented order. The light emitting layer and the first semiconductor layer form a columnar section.

**4 Claims, 5 Drawing Sheets**

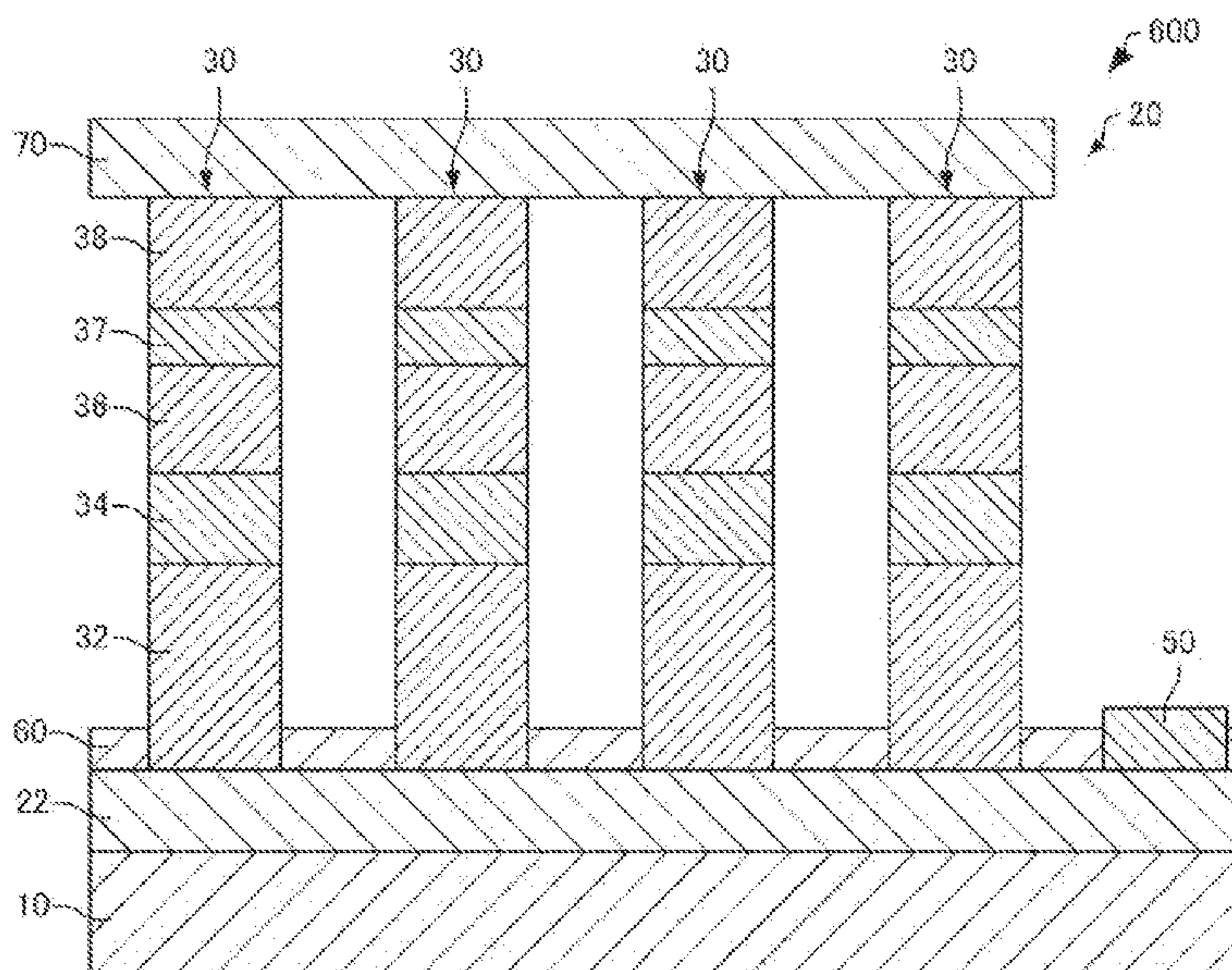

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FIG. 1

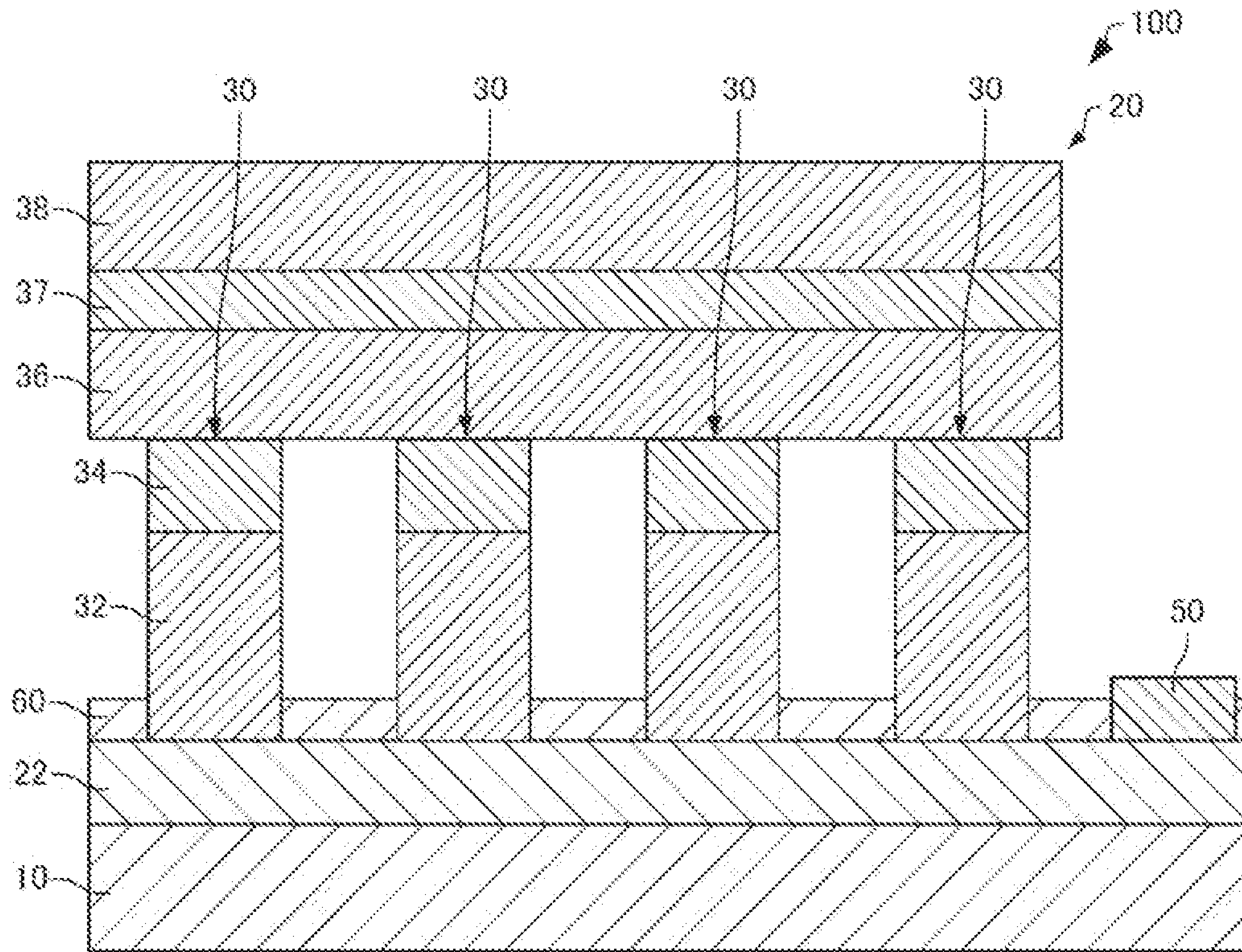



FIG. 2

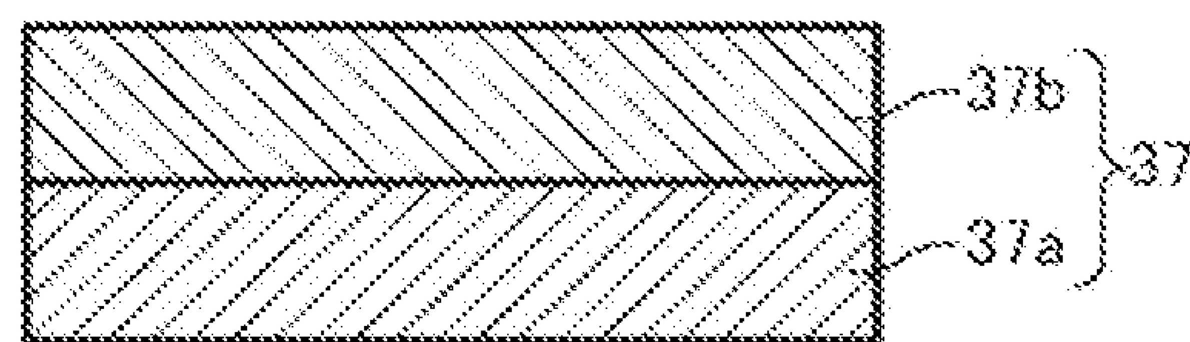



FIG. 3

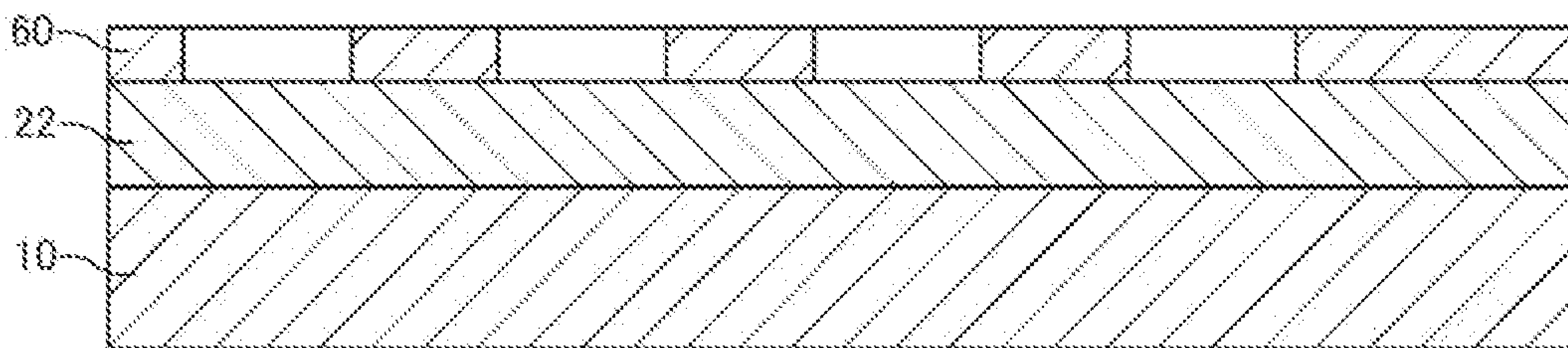


FIG. 4

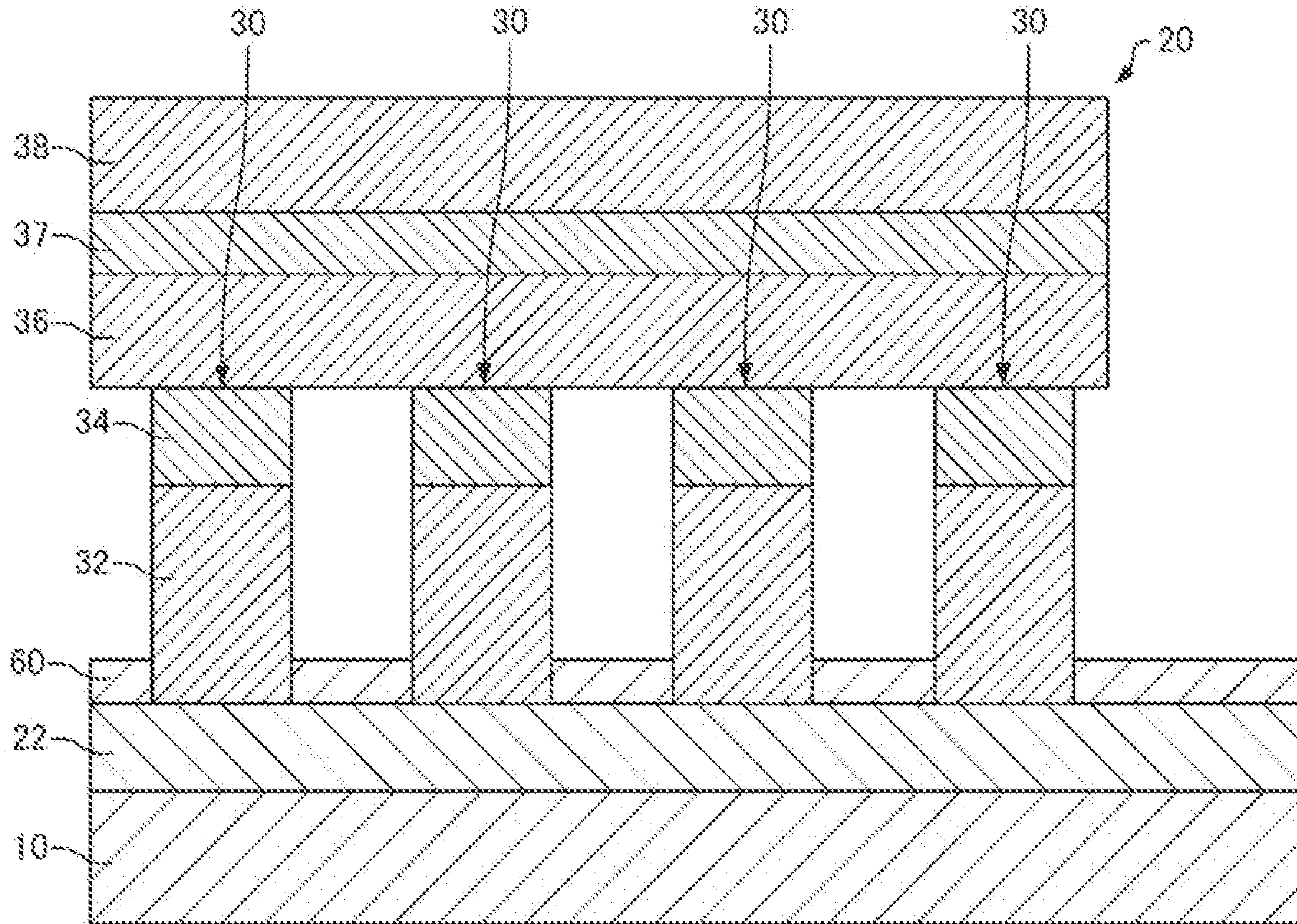



FIG. 5

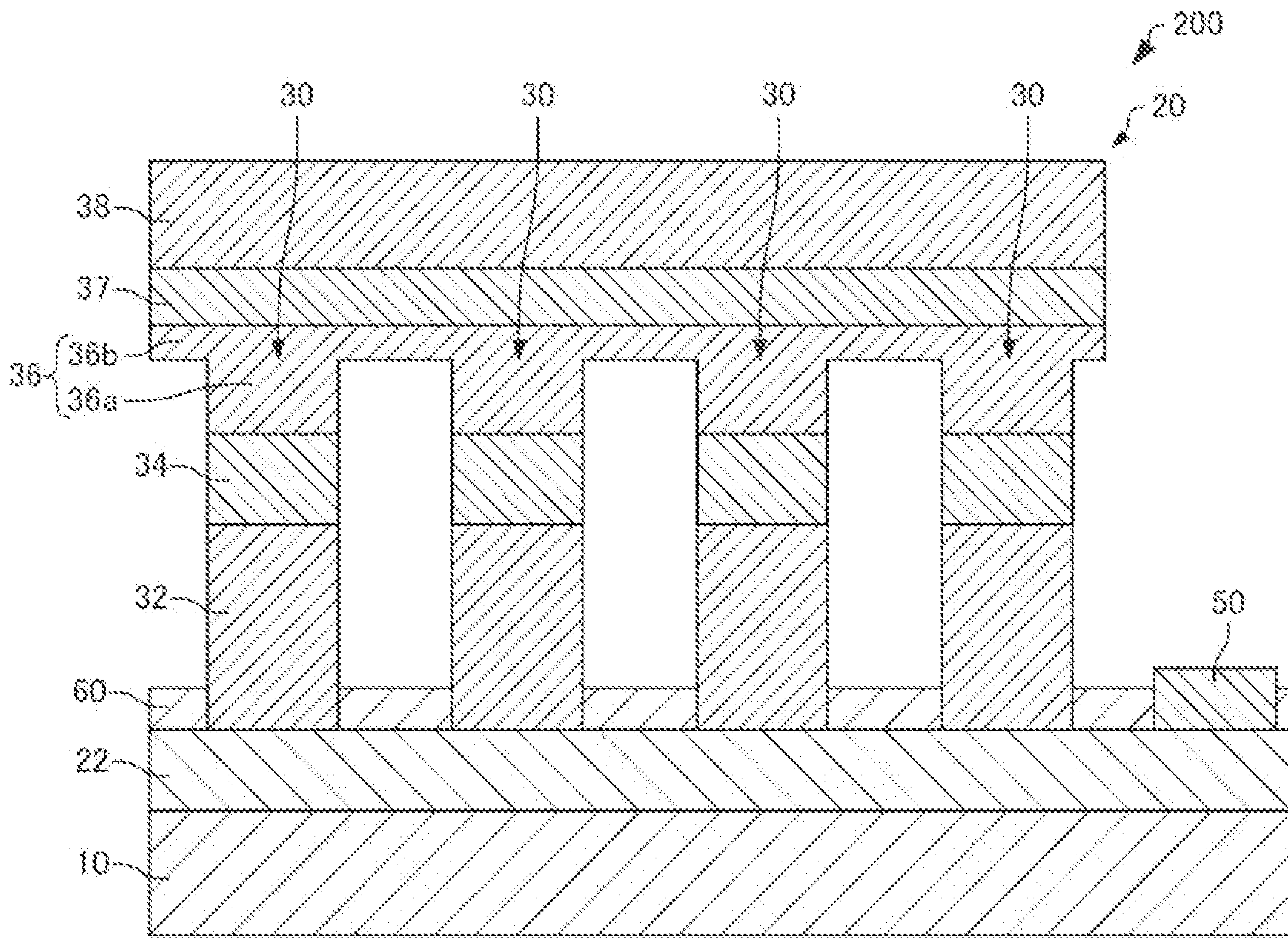


FIG. 6

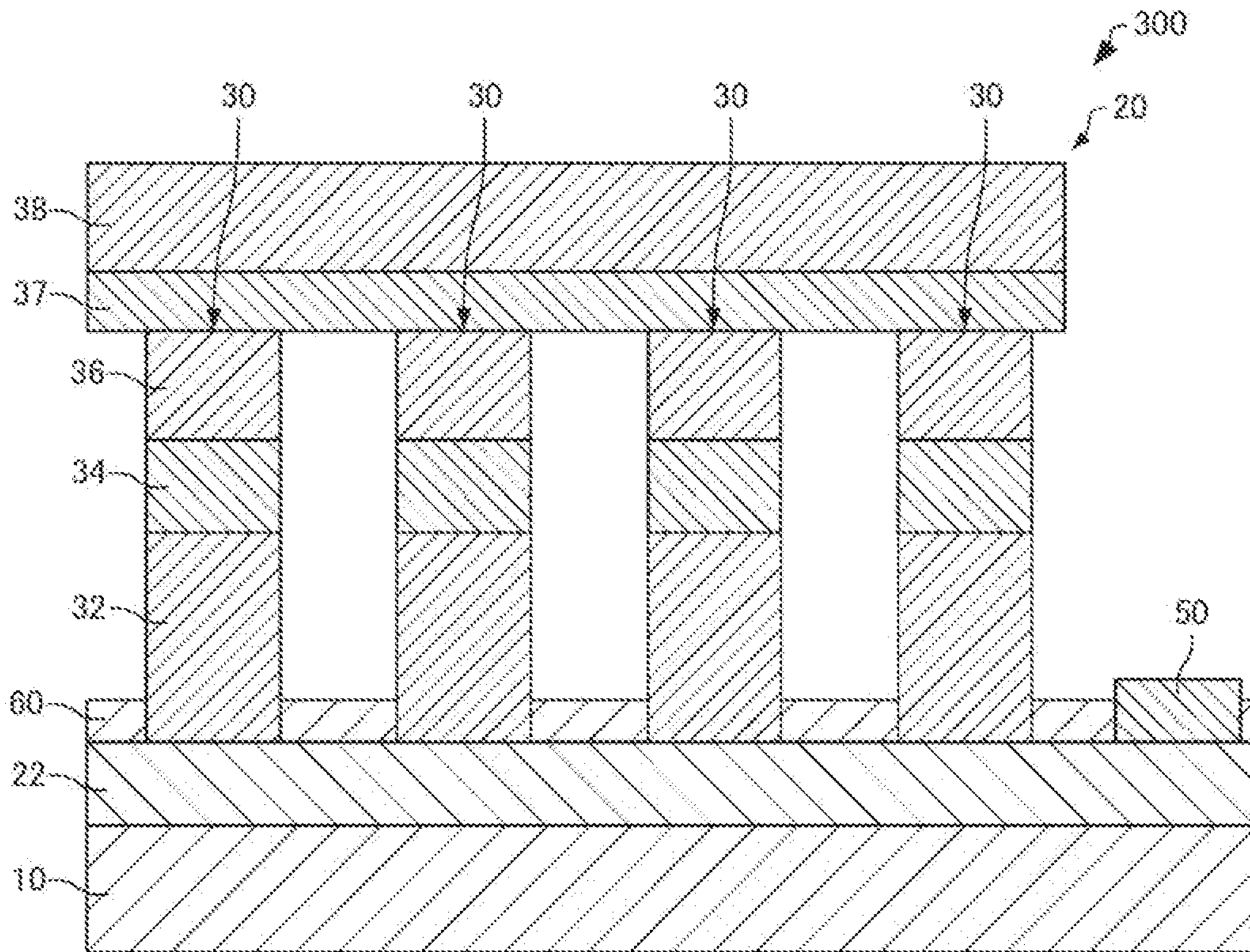



FIG. 7

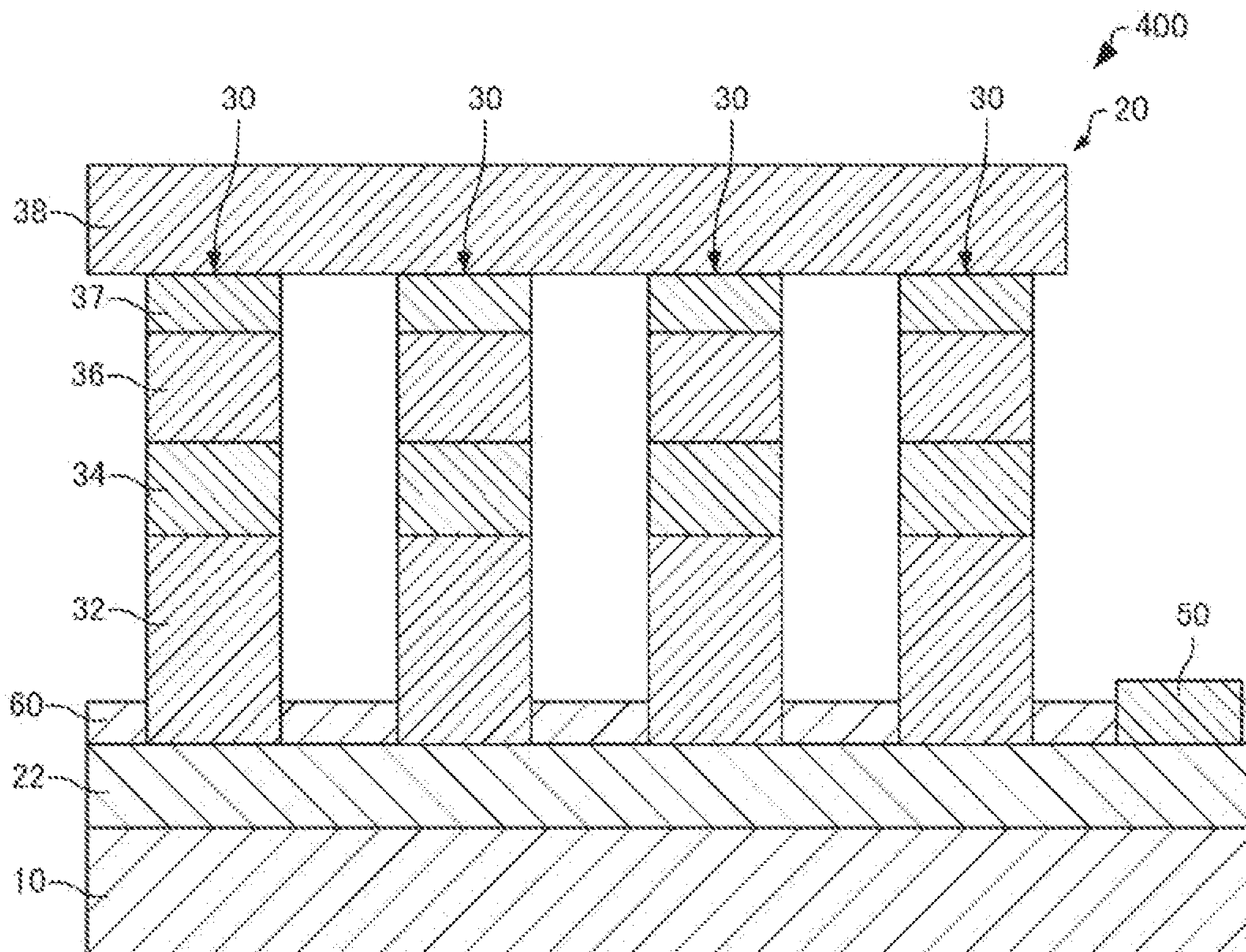


FIG. 8

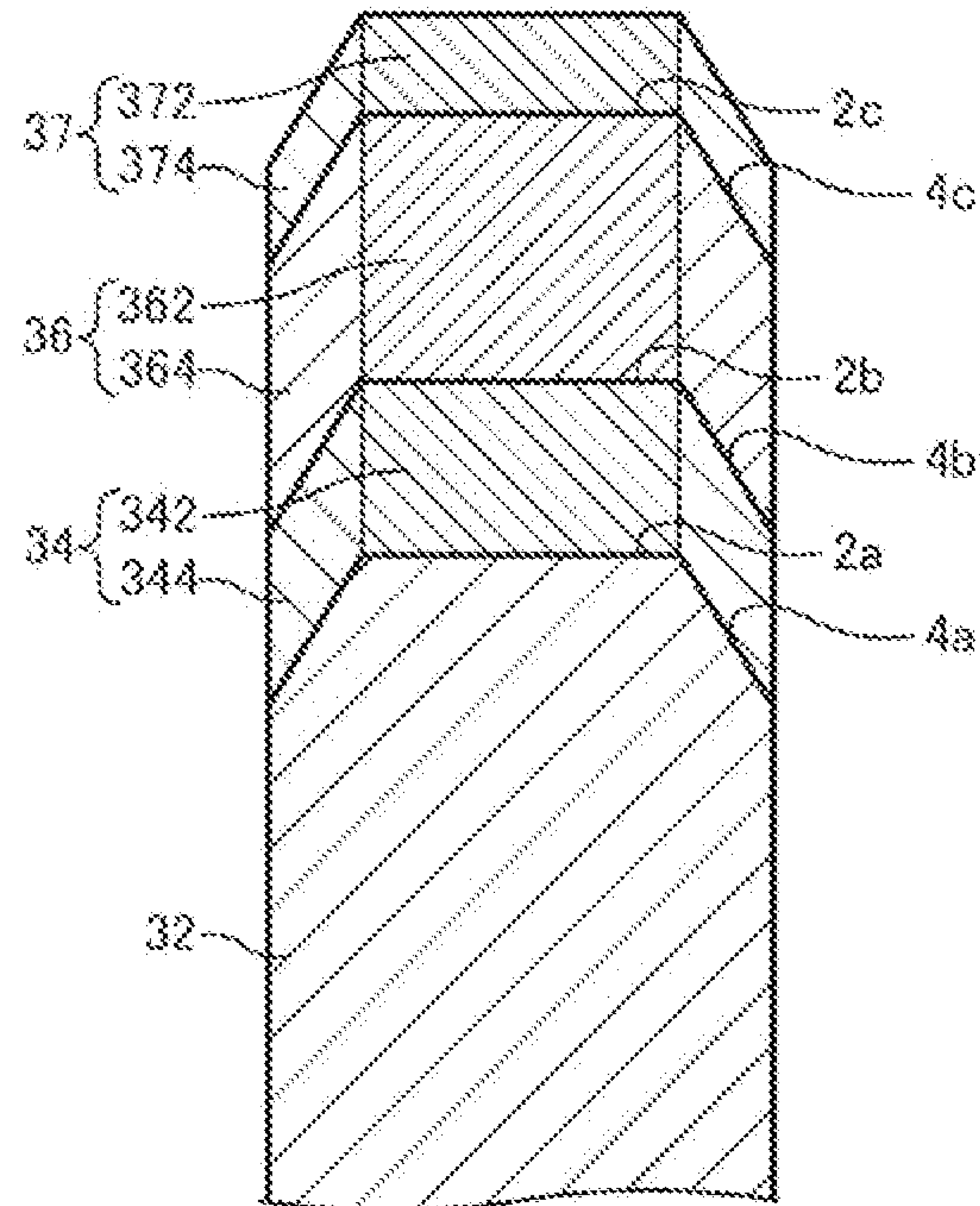



FIG. 9

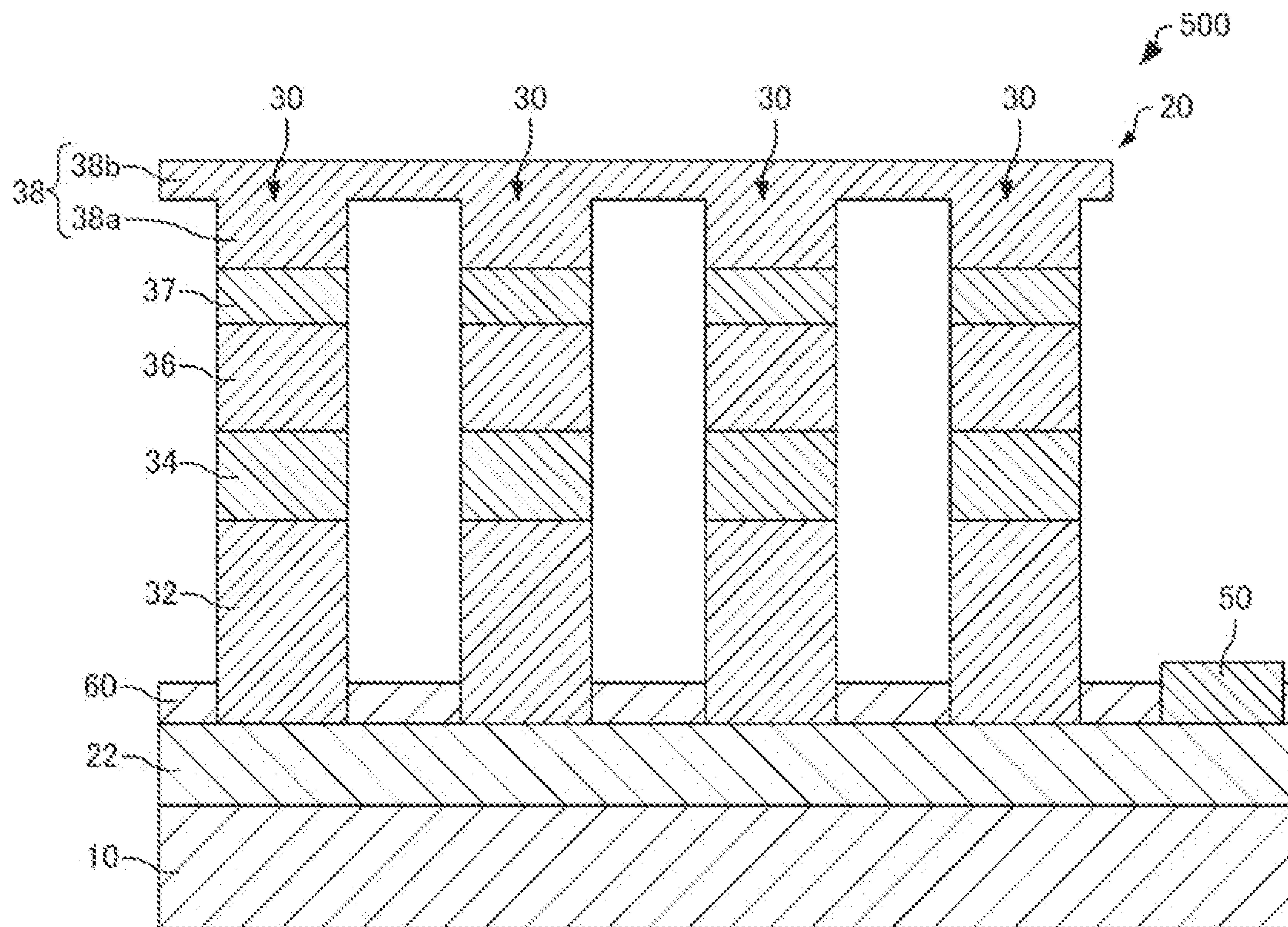


*FIG. 10*

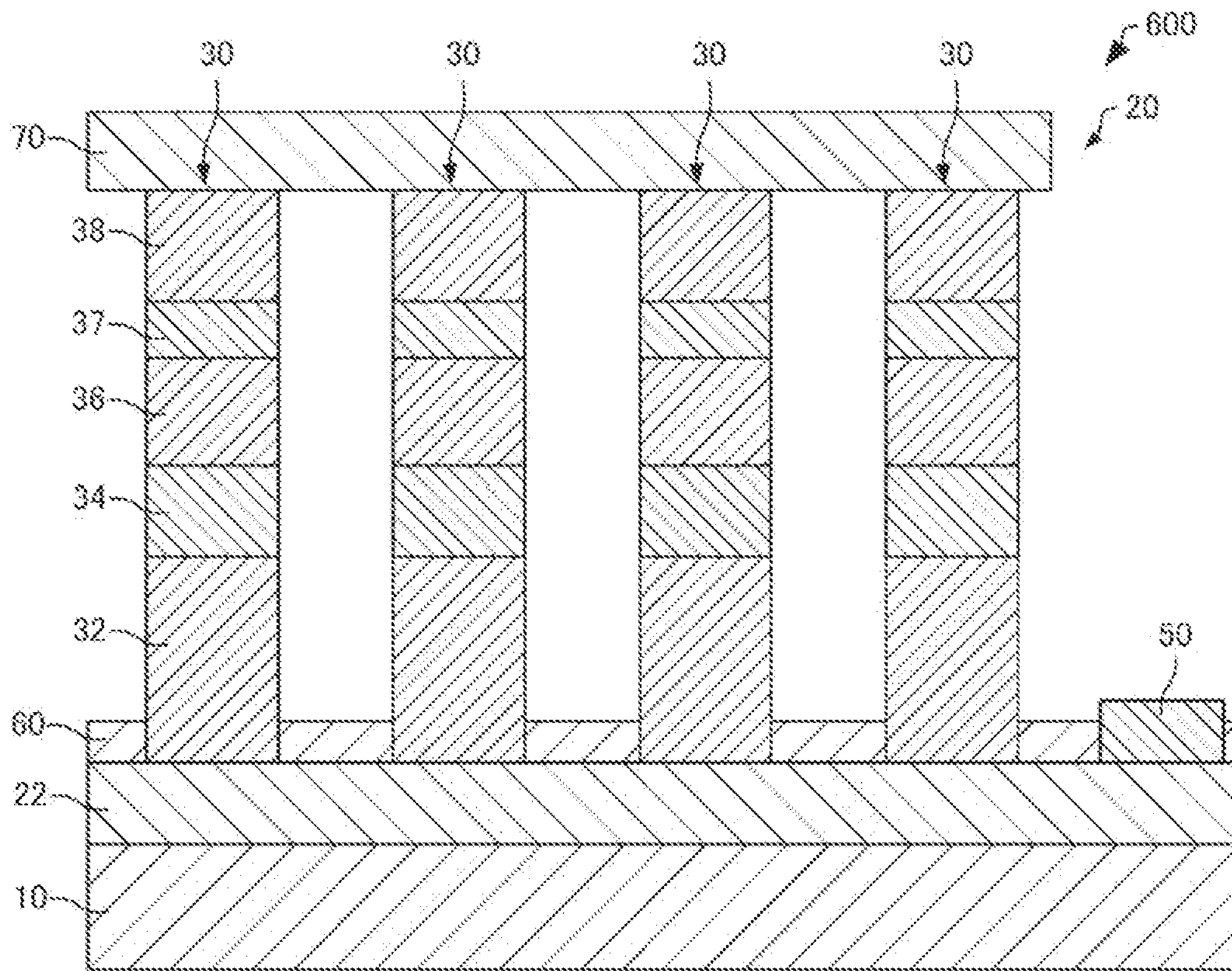
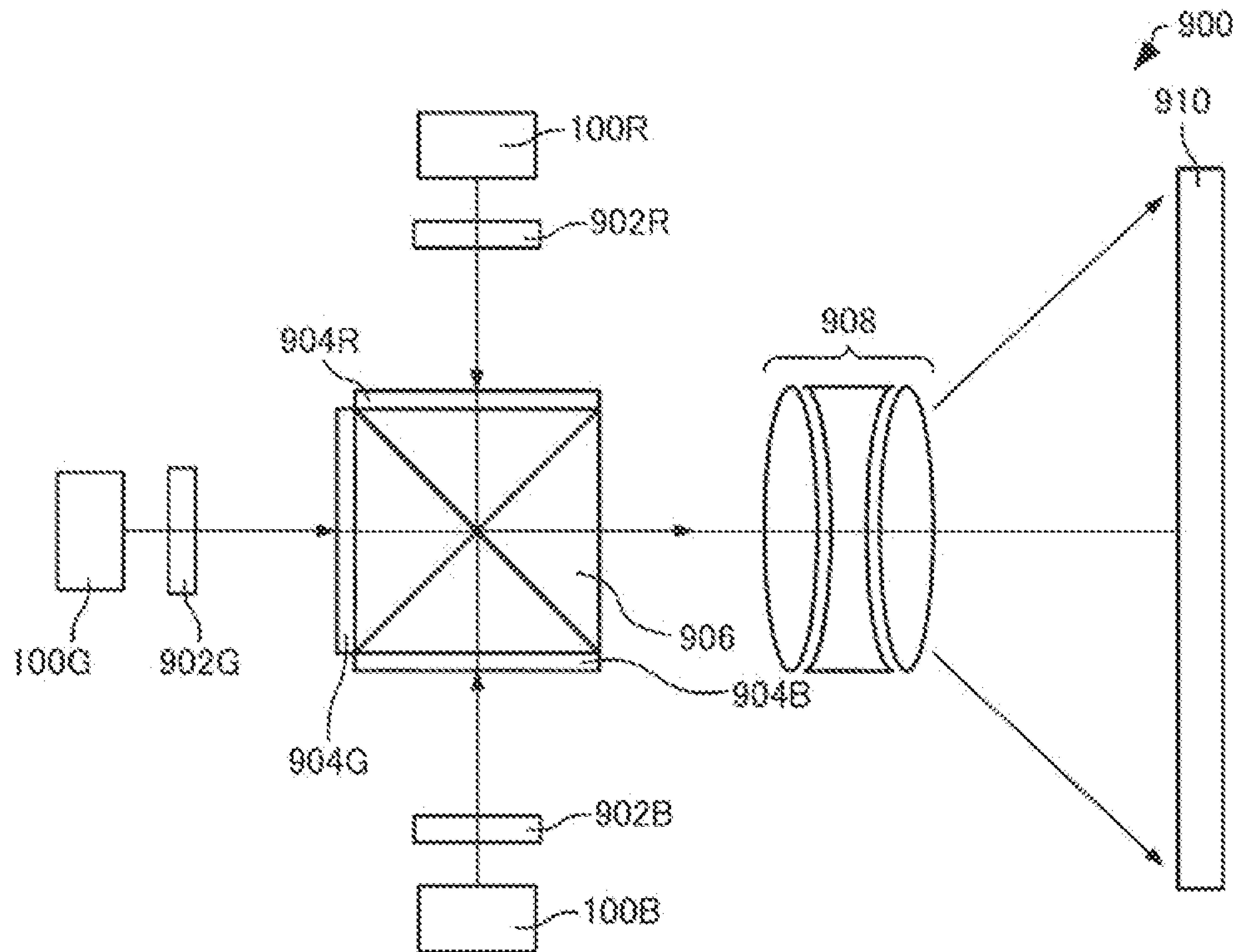



*FIG. 11*



# LIGHT EMITTING APPARATUS AND PROJECTOR

The present application is based on, and claims priority from JP Application Serial Number 2020-039603, filed Mar. 9, 2020, the disclosure of which is hereby incorporated by reference herein in its entirety.

## BACKGROUND

### Technical Field

The present disclosure relates to a light emitting apparatus and a projector.

### Related Art

Semiconductor lasers are expected as a high-luminance, next-generation light source. In particular, a semiconductor laser having a nano-structure called, for example, a nano-column, a nano-wire, a nano-rod, and a nano-pillar, is expected to achieve a light emitting apparatus capable of emitting high-power light having a narrow radiation angle based on a photonic crystal effect.

JP-A-2010-10657 discloses a GaN nano-column LED in which top portions of a plurality of nano-columns formed on a surface of an Si substrate are covered with a transparent electrode. In JP-A-2010-10657, the transparent electrode is made of ITO (indium tin oxide).

In the semiconductor laser including the nano-columns, however, light propagating between the nano-columns cannot be completely confined between cladding layers but leaks to the electrode formed above the nano-columns. Therefore, when the electrode made of ITO is used, the light propagating between the nano-columns is greatly lost due to a large light absorption coefficient of ITO.

## SUMMARY

A light emitting apparatus according to an aspect of the present disclosure includes an electrode and a laminated structure. The laminated structure includes an n-type first semiconductor layer, a light emitting layer, a p-type second semiconductor layer, a tunnel junction layer, an n-type third semiconductor layer. The electrode is electrically connected to the first semiconductor layer. The first semiconductor layer, the light emitting layer, the second semiconductor layer, the tunnel junction layer, and the third semiconductor layer are arranged in a presented order. The light emitting layer and the first semiconductor layer form a columnar section.

A projector according to an aspect of the present disclosure has the aspect of the light emitting apparatus.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view diagrammatically showing a light emitting apparatus according to a first embodiment.

FIG. **2** is a cross-sectional view diagrammatically showing a tunnel junction layer.

FIG. **3** is a cross-sectional view diagrammatically showing one of the steps of manufacturing the light emitting apparatus according to the first embodiment.

FIG. **4** is a cross-sectional view diagrammatically showing one of the steps of manufacturing the light emitting apparatus according to the first embodiment.



FIG. **5** is a cross-sectional view diagrammatically showing a light emitting apparatus according to a second embodiment.

FIG. **6** is a cross-sectional view diagrammatically showing a light emitting apparatus according to a third embodiment.

FIG. **7** is a cross-sectional view diagrammatically showing a light emitting apparatus according to a fourth embodiment.

FIG. **8** is a cross-sectional view diagrammatically showing a columnar section.

FIG. **9** is a cross-sectional view diagrammatically showing a light emitting apparatus according to a fifth embodiment.

FIG. **10** is a cross-sectional view diagrammatically showing a light emitting apparatus according to a sixth embodiment.

FIG. **11** diagrammatically shows a projector according to a seventh embodiment.

## DESCRIPTION OF EXEMPLARY EMBODIMENTS

Preferable embodiments of the present disclosure will be described below in detail with reference to the drawings. It is not intended that the embodiments described below unduly limit the contents of the present disclosure set forth in the appended claims. Further, all configurations described below are not necessarily essential configuration requirements of the present disclosure.

### 1. First Embodiment

#### 1.1. Light Emitting Apparatus

A light emitting apparatus according to a first embodiment will first be described with reference to the drawings. FIG. **1** is a cross-sectional view diagrammatically showing a light emitting apparatus **100** according to the first embodiment.

The light emitting apparatus **100** includes a base **10**, a laminated structure **20**, and an electrode **50**, as shown in FIG. **1**.

The substrate **10** is, for example, an Si substrate, a GaN substrate, or a sapphire substrate.

The laminated structure **20** is provided on the substrate **10**. The laminated structure **20** includes a buffer layer **22**, first semiconductor layers **32**, light emitting layers **34**, a second semiconductor layer **36**, a tunnel junction layer **37**, and a third semiconductor layer **38**.

The buffer layer **22**, the first semiconductor layers **32**, the light emitting layers **34**, the second semiconductor layer **36**, the tunnel junction layer **37**, and the third semiconductor layer **38** are arranged in the presented order from the side facing the substrate **10**. That is, the second semiconductor layer **36** is disposed between the first semiconductor layers **32** and the third semiconductor layer **38**, the light emitting layers **34** are disposed between the first semiconductor layers **32** and the second semiconductor layer **36**, the tunnel junction layer **37** is disposed between the second semiconductor layer **36** and the third semiconductor layer **38**, and the first semiconductor layers **32** are disposed between the substrate **10** and the light emitting layers **34**.

The buffer layer **22** is provided on the substrate **10**. The buffer layer **22** is, for example, an n-type GaN layer to which Si has been doped. A mask layer **60** for forming columnar sections **30** is provided on the buffer layer **22**. The mask

layer **60** is, for example, a titanium layer, a titanium oxide layer, a silicon oxide layer, or an aluminum oxide layer.

The present specification will be described on the assumption that in a lamination direction of the laminated structure **20** (hereinafter also simply referred to as "lamination direction"), the direction from the light emitting layers **34** as a reference toward the second semiconductor layer **36** is called an "upward direction" and the direction from the light emitting layers **34** as the reference toward the first semiconductor layers **32** is called a "downward direction." The "lamination direction of the laminated structure" refers to the direction in which the first semiconductor layers **32** and the light emitting layers **34** are laminated on each other.

The first semiconductor layers **32** are provided on the buffer layer **22**. The first semiconductor layers **32** are provided between the substrate **10** and the light emitting layers **34**. The first semiconductor layers **32** are each an n-type semiconductor layer. The first semiconductor layers **32** are each, for example, an n-type GaN layer to which Si has been doped.

The light emitting layers **34** are provided on the first semiconductor layers **32**. The light emitting layers **34** are provided between the first semiconductor layers **32** and the second semiconductor layer **36**. The light emitting layers **34** produce light when current is injected thereinto. The light emitting layers **34** each have, for example, a multiple quantum well structure in which quantum well structures each formed of an i-type GaN layer and an i-type InGaN layer to each of which no impurity has been doped are layered on each other.

The second semiconductor layer **36** is provided on the light emitting layers **34**. The second semiconductor layer **36** is provided between the light emitting layers **34** and the tunnel junction layer **37**. The second semiconductor layer **36** is a layer having a conductivity type different from that of the first semiconductor layers **32**. The second semiconductor layer **36** is a p-type semiconductor layer. The second semiconductor layer **36** is, for example, a p-type AlGaN layer to which Mg has been doped. The second semiconductor layer **36** may, for example, instead be a p-type GaN layer to which Mg has been doped. The first semiconductor layers **32** and the second semiconductor layer are each a cladding layer having the function of confining the light in the light emitting layers **34**.

The tunnel junction layer **37** is provided on the second semiconductor layer **36**. The tunnel junction layer is provided between the second semiconductor layer **36** and the third semiconductor layer **38**. The tunnel junction layer **37** joins the second semiconductor layer **36** to the third semiconductor layer **38** to each other in the form of a tunnel junction. Current can therefore be injected from the n-type third semiconductor layer **38** into the p-type second semiconductor layer **36**. The tunnel junction layer **37** has a film thickness, for example, smaller than or equal to 50 nm. The tunnel junction layer **37** has a visible light absorption coefficient of, for example, about 100 $cm^{-1}$.

FIG. **2** is a cross-sectional view diagrammatically showing the tunnel junction layer **37**. The tunnel junction layer **37** includes a first layer **37*a*** and a second layer **37*b***.

The first layer **37*a*** is provided on the second semiconductor layer **36**. The first layer **37*a*** is a p-type semiconductor layer. The first layer **37*a*** is, for example, a p-type GaN layer to which high-concentration Mg has been doped. The Mg concentration of the first layer **37*a*** is higher than the Mg concentration of the second semiconductor layer **36**. For example, the Mg concentration of the first layer **37*a*** ranges from $1\times10^{19}$ to $1\times10^{22}$ $cm^{-3}$, which is higher by about one digit than the Mg concentration of the second semiconductor layer **36**. The first layer **37*a*** is not necessarily made of GaN and may, for example, be a nitrite semiconductor layer made of AlN, GaN, InN, or a mixed crystal thereof. The dopant doped into the first layer **37*a*** is not limited to Mg and may instead be another p-type dopant.

The second layer **37*b*** is provided on the first layer **37*a***. The second layer **37*b*** is an n-type semiconductor layer. The second layer **37*b*** is, for example, an n-type GaN layer to which high-concentration Si has been doped. The Si concentration of the second layer **37*b*** is higher than the Si concentration of the first semiconductor layers **32** and the Si concentration of the third semiconductor layer **38**. For example, the Si concentration of the second layer **37*b*** ranges from $1\times10^{19}$ to $1\times10^{22}$ $cm^{-3}$, which is higher by about one digit than the Si concentration of the first semiconductor layers **32**. The second layer **37*b*** is not necessarily made of GaN and may, for example, be a nitrite semiconductor layer made of AlN, GaN, InN, or a mixed crystal thereof. The dopant doped into the second layer **37*b*** is not limited to Si and may instead be another n-type dopant.

The third semiconductor layer **38** is provided on the tunnel junction layer **37**. The third semiconductor layer is an n-type semiconductor layer. The third semiconductor layer **38** is, for example, an n-type GaN layer to which Si has been doped. The third semiconductor layer **38** may, for example, be an n-type AlGaN layer to which Si has been doped. The third semiconductor layer **38** is joined in the form of a tunnel junction to the second semiconductor layer **36** via the tunnel junction layer **37**.

The third semiconductor layer **38** functions as an electrode for injecting current into the light emitting layers **34**. The third semiconductor layer **38** diffuses the current in the in-plane direction of the laminated structure **20**, which is the direction perpendicular to the lamination direction, and supplies the plurality of columnar sections with the current. The light emitting apparatus **100** therefore needs no transparent electrode made, for example, of ITO.

The visible light absorption coefficient of ITO is, for example, about 2000 $cm^{-1}$, which is a large light absorption coefficient. The light absorption coefficient of the tunnel junction layer **37** is smaller than the light absorption coefficient of ITO by about one digit. The light absorption coefficient of the third semiconductor layer **38**, which is an n-type GaN layer, is extremely small. The light absorption coefficient of the third semiconductor layer **38**, which is an n-type GaN layer, is smaller than the light absorption coefficient of ITO and smaller than the light absorption coefficient of the second semiconductor layer **36**, which is a p-type GaN layer.

Therefore, in the light emitting apparatus **100**, the third semiconductor layer **38**, which is joined in the form of a tunnel junction to the second semiconductor layer **36** via the tunnel junction layer **37**, is used as an electrode, whereby loss of the light propagating between the columnar sections **30** can be reduced as compared, for example, with the case where an electrode made of ITO is used.

The electrode **50** is provided on the buffer layer **22**. The buffer layer **22** may be in ohmic contact with the electrode **50**. The electrode **50** is electrically connected to the first semiconductor layers **32**. In the example shown in FIG. **1**, the electrode **50** is electrically connected to the first semiconductor layers **32** via the buffer layer **22**. The first electrode **50** is one of the electrodes for injecting current into the light emitting layers **34**. That is, in the light emitting apparatus **100**, the electrode **50** and the third semiconductor layer **38** inject current into the light emitting layers **34**. The

first electrode **50** is, for example, a laminated structure of a Cr layer, an Ni layer, and an Au layer laminated in the presented order from the side facing the buffer layer **22**.

The first semiconductor layers **32** and the light emitting layers **34** form the columnar sections **30**. The laminated structure **20** includes a plurality of columnar sections **30**. The columnar sections **30** are provided on the buffer layer **22**. The columnar sections **30** each have a columnar shape protruding upward from the buffer layer **22**. The columnar sections **30** are each also called, for example, a nano-column, a nano-wire, a nano-rod, and a nano-pillar. The columnar sections **30** each have, for example, a polygonal or circular planar shape.

The columnar sections **30** each have a diameter, for example, greater than or equal to 50 nm but smaller than or equal to 500 nm. When the diameter of each of the columnar sections **30** is smaller than or equal to 500 nm, high-quality-crystal light emitting layers **34** can be produced, whereby distortion intrinsically present in the light emitting layers **34** can be reduced. The light produced in the light emitting layers **34** can thus be efficiently amplified. The plurality of columnar sections **30** have, for example, the same diameter.

In a case where the columnar sections **30** each have a circular planar shape, the term "the diameter of the columnar sections" refers to the diameter of the circular shape, and when the columnar sections **30** each have a non-circular planar shape, the term refers to the diameter of a minimum circle containing the non-circular shape therein. For example, when the columnar sections **30** each have a polygonal planar shape, the terms refers to the diameter of a minimum circle containing the polygonal shape therein, and when the columnar sections **30** each have an elliptical planar shape, the term refers to the diameter of a minimum circle containing the elliptical shape therein.

The columnar sections **30** are located at a plurality of locations. The distance between adjacent columnar sections **30** is, for example, greater than or equal to 1 nm but smaller than or equal to 500 nm. The plurality of columnar sections **30** are arranged in a predetermined direction at predetermined intervals in the plan view viewed in the lamination direction. The plurality of columnar sections **30** are arranged in a triangular lattice. The plurality of columnar sections **30** are not necessarily arranged in a specific shape and may be arranged in a square lattice. The plurality of columnar sections **30** can provide the photonic crystal effect.

The "interval between the columnar sections" is the distance between the centers of columnar sections **30** adjacent to each other in the predetermined direction. In the case where the columnar sections **30** each have a circular planar shape, the term "the centers of the columnar sections" each refers to the center of the circle, and when the columnar sections **30** each have a non-circular planar shape, the term refers to the center of a minimum circle containing the non-circular shape therein. For example, when the columnar sections **30** each have a polygonal planar shape, the term refers to the center of a minimum circle containing the polygonal shape therein, and when the columnar sections **30** each have an elliptical planar shape, the term refers to the center of a minimum circle containing the elliptical shape therein.

The second semiconductor layer **36** is a single layer so provided as to extend over the plurality of columnar sections **30**. That is, the second semiconductor layer **36** does not form the columnar sections **30**. Similarly, the tunnel junction layer **37** is a single layer so provided as to extend over the plurality of columnar sections **30**, so that the tunnel junction layer **37** does not form the columnar sections **30**. Similarly, the third semiconductor layer **38** is a single layer so provided as to extend over the plurality of columnar sections **30**, so that the third semiconductor layer **38** does not form the columnar sections **30**.

In the light emitting apparatus **100**, each set of the p-type second semiconductor layer **36**, the light emitting layer **34**, and the n-type first semiconductor layer **32** form a pin diode. In the light emitting apparatus **100**, when forward bias voltage for the pin diode is applied to the space between the electrode **50** and the third semiconductor layer **38**, current is injected into the light emitting layers **34**, whereby electrons and holes recombine with each other in the light emitting layers **34**. The recombination causes light emission. The first semiconductor layers **32** and the second semiconductor layer **36** cause the light produced in the light emitting layers **34** to propagate in the in-plane direction perpendicular to the lamination direction and form a standing wave based on the photonic crystal effect provided by the plurality of columnar sections **30**, and the standing wave receives gain in the light emitting layers **34** to achieve laser oscillation. The light emitting apparatus **100** then outputs positive first order diffracted light and negative first order diffracted light as the laser light in the lamination direction.

The light emitting apparatus **100** can provide, for example, the following effects and advantages.

In the light emitting apparatus **100**, the n-type first semiconductor layers **32**, the i-type light emitting layers **34**, the p-type second semiconductor layer **36**, the tunnel junction layer **37**, and the n-type third semiconductor layer **38** are arranged in the presented order from the side facing the substrate **10**. In the light emitting apparatus **100**, the p-type second semiconductor layer **36** is joined in the form of a tunnel junction to the n-type third semiconductor layer **38** via the tunnel junction layer **37**, whereby the n-type third semiconductor layer **38** can inject current into the p-type second semiconductor layer **36** via the tunnel junction layer **37**. The third semiconductor layer can therefore be used as an electrode for injecting current into the light emitting layers **34**. Since the n-type third semiconductor layer **38** has an extremely small light absorption coefficient, whereby loss of the light propagating between the columnar sections **30** can be reduced as compared, for example, with the case where an electrode made of ITO is used.

For example, even when an electrode made of ITO is used, reducing the thickness of the ITO electrode can reduced the optical loss. A thin electrode, however, results in an increase in electrical resistance and hence deterioration of the characteristics of the pin diodes. In the light emitting apparatus **100**, the n-type third semiconductor layer **38** having a small light absorption coefficient is used as the electrode, the optical loss can be reduced even when the thickness of the electrode is not reduced. The light emitting apparatus **100** can therefore be a low-resistance, low-optical-loss light emitting apparatus.

### 1.2. Method for Manufacturing Light Emitting Apparatus

A method for manufacturing the light emitting apparatus **100** according to the first embodiment will next be described with reference to the drawings. FIGS. **3** and **4** are cross-sectional views diagrammatically each showing one of the steps of manufacturing the light emitting apparatus **100** according to the first embodiment.

The buffer layer **22** is epitaxially grown on the substrate **10**, as shown in FIG. **3**. Examples of the epitaxial growth

method may include a metal organic chemical vapor deposition (MOCVD) method and a molecular beam epitaxy (MBE) method.

The mask layer **60** is then formed on the buffer layer **22**. The mask layer **60** is provided with a plurality of holes for forming columnar sections **30**.

The mask layer **60** is used as a mask to epitaxially grow the first semiconductor layers **32**, the light emitting layers **34**, the second semiconductor layer **36**, the tunnel junction layer **37**, and the third semiconductor layer **38** on the buffer layer **22**, as shown in FIG. **4**. Examples of the epitaxial growth method may include the MOCVD and MBE methods.

To epitaxially grow the first semiconductor layers **32** and the light emitting layers **34**, the epitaxial growth is performed under conditions that allow the layers **32** and to grow in the lamination direction. The first semiconductor layers **32** and the light emitting layers **34** thus form the columnar sections **30**. To epitaxially grow the second semiconductor layer **36**, the epitaxial growth is performed under conditions that allow the layer **36** to grow not only in the lamination direction but in the in-plane direction perpendicular to the lamination direction. The second semiconductor layer **36** thus forms a single layer so provided not as to form the columnar sections **30** but to extend over the plurality of columnar sections **30**. The tunnel junction layer **37** and the third semiconductor layer formed on the second semiconductor layer **36** are each formed as a single layer that extends over the plurality of columnar sections **30**, as in the case of the second semiconductor layer **36**.

The electrode **50** is formed on the buffer layer **22**, as shown in FIG. **1**. The electrode **50** is formed, for example, in vacuum evaporation.

The light emitting apparatus **100** can be manufactured by carrying out the steps described above.

## 2. Second Embodiment

### 2.1. Light Emitting Apparatus

A light emitting apparatus according to a second embodiment will next be described with reference to the drawings. FIG. **5** is a cross-sectional view diagrammatically showing a light emitting apparatus **200** according to the second embodiment. In the following description of the light emitting apparatus **200** according to the second embodiment, a member having the same function as that of a constituent member of the light emitting apparatus **100** according to the first embodiment described above has the same reference character and will not be described in detail.

In the light emitting apparatus **100** described above, the first semiconductor layers **32** and the light emitting layers **34** form the columnar sections **30**, as shown in FIG. **1**.

In contrast, in the light emitting apparatus **200**, the first semiconductor layers **32**, the light emitting layers **34**, and part of the second semiconductor layer **36** form the columnar sections **30**, as shown in FIG. **5**.

The second semiconductor layer **36** includes columnar sections **36***a* and a layer-shaped section **36***b*, as shown in FIG. **5**.

The columnar sections **36***a* are sections of the second semiconductor layer **36** that are the sections forming the columnar sections **30**. The columnar sections **36***a* are in contact with the light emitting layers **34**. The layer-shaped section **36***b* is a section of the second semiconductor layer **36** that is the section having the shape of a layer and so provided as to extend over the plurality of columnar sections **30**. That is, the layer-shaped section **36***b* does not form the columnar sections **30**. The layer-shaped section **36***b* is in contact with the tunnel junction layer **37**.

The light emitting apparatus **200** allows reduction in the loss of the light propagating between the columnar sections **30**, as the light emitting apparatus **100** described above does.

### 2.2. Method for Manufacturing Light Emitting Apparatus

In a method for manufacturing the light emitting apparatus **200**, to epitaxially grow the second semiconductor layer **36**, the epitaxial growth is performed under conditions that allow the layer **36** to grow in the lamination direction to form the columnar sections **36***a*, and the epitaxial growth is then performed under the conditions that allow the layer **36** to grow not only in the lamination direction but in the in-plane direction to form the layer-shaped section **36***b*. The other steps are the same as those of the method for manufacturing the light emitting apparatus **100** described above.

## 3. Third Embodiment

### 3.1. Light Emitting Apparatus

A light emitting apparatus according to a third embodiment will next be described with reference to the drawings. FIG. **6** is a cross-sectional view diagrammatically showing a light emitting apparatus **300** according to the third embodiment. In the following description of the light emitting apparatus **300** according to the third embodiment, a member having the same function as that of a constituent member of the light emitting apparatus **100** according to the first embodiment described above has the same reference character and will not be described in detail.

In the light emitting apparatus **100** described above, the first semiconductor layers **32** and the light emitting layers **34** form the columnar sections **30**, as shown in FIG. **1**.

In contrast, in the light emitting apparatus **300**, the first semiconductor layers **32**, the light emitting layers **34**, and the second semiconductor layers **36** form the columnar sections **30**, as shown in FIG. **6**.

The light emitting apparatus **300** allows reduction in the loss of the light propagating between the columnar sections **30**, as the light emitting apparatus **100** described above does.

### 3.2. Method for Manufacturing Light Emitting Apparatus

In a method for manufacturing the light emitting apparatus **300**, to epitaxially grow the second semiconductor layers **36**, the epitaxial growth is performed under conditions that allow the layer **36** to grow in the lamination direction, and to epitaxially grow the tunnel junction layer **37**, the epitaxial growth is performed under conditions that allow the layer **37** to grow not only in the lamination direction but in the in-plane direction. The other steps are the same as those of the method for manufacturing the light emitting apparatus **100** described above.

## 4. Fourth Embodiment

### 4.1. Light Emitting Apparatus

A light emitting apparatus according to a fourth embodiment will next be described with reference to the drawings. FIG. **7** is a cross-sectional view diagrammatically showing

a light emitting apparatus **400** according to the fourth embodiment. In the following description of the light emitting apparatus **400** according to the fourth embodiment, a member having the same function as that of a constituent member of the light emitting apparatus **100** according to the present embodiment described above has the same reference character and will not be described in detail.

In the light emitting apparatus **100** described above, the first semiconductor layers **32** and the light emitting layers **34** form the columnar sections **30**, as shown in FIG. **1**.

In contrast, in the light emitting apparatus **400**, the first semiconductor layers **32**, the light emitting layers **34**, the second semiconductor layers **36**, and the tunnel junction layers **37** form the columnar sections **30**, as shown in FIG. **7**.

FIG. **8** is a cross-sectional view diagrammatically showing one of the columnar sections **30**.

The first semiconductor layer **32** is, for example, made of a GaN crystal having a wurtzite crystal structure. The first semiconductor layer **32** has a c surface **2***a* and a facet surface **4***a*. The c surface **2***a* is, for example, parallel to the principal surface of the substrate **10** shown in FIG. **7**. The principal surface of the substrate **10** is the surface on which the laminated structure **20** is provided. The facet surface **4***a*, for example, inclines with respect to the principal surface of the substrate **10**.

The light emitting layer **34** has a c surface area **342**, which is provided on the c surface **2***a* of the first semiconductor layer **32**, and a facet surface area **344**, which is provided on the facet surface **4***a* of the first semiconductor layer **32**. The c surface area **342** is an area of the light emitting layer **34** that is an area having undergone crystal growth under the influence of the c surface **2***a* of the first semiconductor layer **32**. The facet surface area **344** is an area of the light emitting layer **34** that is an area having undergone crystal growth under the influence of the facet surface **4***a* of the first semiconductor layer **32**. The c surface area **342** is surrounded by the facet surface area **344** when viewed in the lamination direction.

The c surface area **342**, which undergoes crystal growth under the influence of the c surface **2***a* of the first semiconductor layer **32**, is likely to capture In, as compared with the facet surface **344**. The In concentration of the c surface area **342** is therefore higher than the In concentration of the facet surface area **344**.

The light emitting layer **34** has a c surface **2***b* and a facet surface **4***b*. The c surface **2***b* is, for example, parallel to the principal surface of the substrate **10** shown in FIG. **7**. The facet surface **4***b*, for example, inclines with respect to the principal surface of the substrate **10**.

The second semiconductor layer **36** has a c surface area **362**, which is provided on the c surface **2***b* of the light emitting layer **34**, and a facet surface area **364**, which is provided on the facet surface **4***b* of the light emitting layer **34**. The c surface area **362** is an area of the second semiconductor layer **36** that is an area having undergone crystal growth under the influence of the c surface **2***b* of the light emitting layer **34**. The facet surface area **364** is an area of the second semiconductor layer **36** that is an area having undergone crystal growth under the influence of the facet surface **4***b* of the light emitting layer **34**. The c surface area **362** is surrounded by the facet surface area **364** when viewed in the lamination direction.

The second semiconductor layer **36** has a c surface **2***c* and a facet surface **4***c*. The c surface **2***c* is, for example, parallel to the principal surface of the substrate **10** shown in FIG. **7**. The facet surface **4***c*, for example, inclines with respect to the principal surface of the substrate **10**.

The tunnel junction layer **37** has a c surface area **372**, which is provided on the c surface **2***c* of the second semiconductor layer **36**, and a facet surface area **374**, which is provided on the facet surface **4***c* of the second semiconductor layer **36**. The c surface area **372** is an area of the tunnel junction layer **37** that is an area having undergone crystal growth under the influence of the c surface **2***c* of the second semiconductor layer **36**. The facet surface area **374** is an area of the tunnel junction layer **37** that is an area having undergone crystal growth under the influence of the facet surface **4***c* of the second semiconductor layer **36**. The c surface area **372** is surrounded by the facet surface area **374** when viewed in the lamination direction.

The c surface area **372**, which undergoes crystal growth under the influence of the c surface **2***c* of the second semiconductor layer **36**, is likely to capture impurities, as compared with the facet surface area **374**. The impurity concentration of the c surface area **372** is therefore higher than the impurity concentration of the facet surface area **374**. The c surface area **372** is therefore likely to provide the tunnel effect as compared with the facet surface area **374**. That is, the electrical resistance of the c surface area **372** is smaller than the electrical resistance of the facet surface area **374**. A current narrowing structure that selectively injects current from the c surface area **372** can therefore be formed in the tunnel junction layer **37**. As a result, current can be efficiently injected into the c surface area **342** of the light emitting layer **34**, which is the area having the high In concentration.

Further, in the light emitting apparatus **400**, the tunnel junction layers **37** form the columnar sections **30**. Therefore, in the light emitting apparatus **400**, the tunnel junction layers **37** can be made of a high-quality crystal having a reduced amount of crystal defects, whereby deterioration of the characteristics of the tunnel junction layers **37** due to introduction of crystal deflects can be reduced.

The light emitting apparatus **400** allows reduction in the loss of the light propagating between the columnar sections **30**, as the light emitting apparatus **100** does.

### 4.2. Method for Manufacturing Light Emitting Apparatus

In a method for manufacturing the light emitting apparatus **400**, to epitaxially grow the second semiconductor layers **36** and the tunnel junction layers **37**, the epitaxial growth is performed under conditions that allow the layers and **37** to grow in the lamination direction. To epitaxially grow the third semiconductor layer **38**, the epitaxial growth is performed under conditions that allow the layer **38** to grow not only in the lamination direction but in the in-plane direction. The other steps are the same as those of the method for manufacturing the light emitting apparatus **100** described above.

## 5. Fifth Embodiment

### 5.1. Light Emitting Apparatus

A light emitting apparatus according to a fifth embodiment will next be described with reference to the drawings. FIG. **9** is a cross-sectional view diagrammatically showing a light emitting apparatus **500** according to the fifth embodiment. In the following description of the light emitting apparatus **500** according to the fifth embodiment, a member

having the same function as that of a constituent member of the light emitting apparatus **100** according to the present embodiment described above has the same reference character and will not be described in detail.

In the light emitting apparatus **100** described above, the first semiconductor layers **32** and the light emitting layers **34** form the columnar sections **30**, as shown in FIG. **1**.

In contrast, in the light emitting apparatus **500**, the first semiconductor layers **32**, the light emitting layers **34**, the second semiconductor layers **36**, the tunnel junction layers **37**, and part of the third semiconductor layer **38** form the columnar sections **30**, as shown in FIG. **9**.

The third semiconductor layer **38** includes columnar sections **38***a* and a layer-shaped section **38***b*, as shown in FIG. **9**.

The columnar sections **38***a* are sections of the third semiconductor layer **38** that are the sections forming the columnar sections **30**. The columnar sections **38***a* are in contact with the tunnel junction layers **37**. The layer-shaped section **38***b* is a section of the third semiconductor layer **38** that is the section having the shape of a layer and so provided as to extend over the plurality of columnar sections **30**. That is, the layer-shaped section **38***b* does not form the columnar sections **30**. In the light emitting apparatus **500**, the layer-shaped section **38***b* diffuses current in the in-plane direction and supplies the plurality of columnar sections **30** with the current.

In the light emitting apparatus **500**, the second semiconductor layers **36**, the tunnel junction layers **37**, and part of the third semiconductor layer **38** form the columnar sections **30**. The in-plane-direction average refractive index of the portion above the light emitting layers **34** in the laminated structure **20**, that is, the portion shifted from the light emitting layers **34** toward the third semiconductor layer **38** can therefore be lowered as compared, for example, with the case where the third semiconductor layer **38** does not form the columnar sections **30**. Leakage of the light produced in the light emitting layers **34** toward the third semiconductor layer **38** can therefore be reduced in the light emitting apparatus **500**.

In the light emitting apparatus **500**, the tunnel junction layers **37** form the columnar sections **30**, whereby a current narrowing structure can be formed in each of the tunnel junction layers **37**, as in the light emitting apparatus **400**.

In the light emitting apparatus **500**, in which the tunnel junction layers **37** form the columnar sections **30**, the tunnel junction layers **37** can be made of a high-quality crystal having a reduced amount of crystal defects, whereby deterioration of the characteristics of the tunnel junction layers **37** due to introduction of crystal deflects can be reduced.

The light emitting apparatus **500** allows reduction in the loss of the light propagating between the columnar sections **30**, as the light emitting apparatus **100** does.

### 5.2. Method for Manufacturing Light Emitting Apparatus

In a method for manufacturing the light emitting apparatus **500**, to epitaxially grow the second semiconductor layers **36** and the tunnel junction layers **37**, the epitaxial growth is performed under conditions that allow the layers **36** and **37** to grow in the lamination direction. To epitaxially grow the third semiconductor layer **38**, the epitaxial growth is performed under conditions that allow the layer **38** to grow in the lamination direction to form the columnar sections **38***a*, and the epitaxial growth is then performed under conditions that allow the layer **38** to grow not only in the lamination direction but in the in-plane direction to form the layer-shaped section **38***b*. The other steps are the same as those of the method for manufacturing the light emitting apparatus **100** described above.

## 6. Sixth Embodiment

### 6.1. Light Emitting Apparatus

A light emitting apparatus according to a sixth embodiment will next be described with reference to the drawings. FIG. **10** is a cross-sectional view diagrammatically showing a light emitting apparatus **600** according to a sixth embodiment. In the following description of the light emitting apparatus **600** according to the sixth embodiment, a member having the same function as that of a constituent member of the light emitting apparatus **100** according to the present embodiment described above has the same reference character and will not be described in detail.

In the light emitting apparatus **100** described above, the first semiconductor layers **32** and the light emitting layers **34** form the columnar sections **30**, as shown in FIG. **1**.

In contrast, in the light emitting apparatus **600**, the first semiconductor layers **32**, the light emitting layers **34**, the second semiconductor layers **36**, the tunnel junction layers **37**, and the third semiconductor layers **38** form the columnar sections **30**, as shown in FIG. **10**. The light emitting apparatus **600** includes the electrode **50** (hereinafter also referred to as "first electrode **50**") and a second electrode **70**, which is an electrode that diffuses current in the in-plane direction and supplies the plurality of columnar sections **30** with the current.

The second electrode **70** is a transparent electrode that transmits the light produced in the light emitting layer **34**. The second electrode **70** is made, for example, of ITO. The second electrode **70** is a single layer so provided as to extend over the plurality of columnar sections **30**.

In the light emitting apparatus **600**, the third semiconductor layers **38** are provided between the light emitting layers **34** and the second electrode **70**. The second electrode **70** can therefore be shifted away from the light emitting layers **34** as compared with a case where no third semiconductor layer **38** is provided between the light emitting layers **34** and the second electrode **70**. Therefore, in the light emitting apparatus **600**, leakage of the light propagating between the columnar sections **30** to the second electrode **70** can be reduced, whereby the loss of the light propagating between the columnar sections **30** can be reduced.

In the light emitting apparatus **600**, the tunnel junction layers **37** form the columnar sections **30**, whereby a current narrowing structure can be formed in each of the tunnel junction layers **37**, as in the light emitting apparatuses **400** and **500**.

In the light emitting apparatus **600**, in which the tunnel junction layers **37** form the columnar sections **30**, the tunnel junction layers **37** can be made of a high-quality crystal having a reduced amount of crystal defects, whereby deterioration of the characteristics of the tunnel junction layers **37** due to introduction of crystal deflects can be reduced, as in the light emitting apparatuses **400** and **500**.

In the light emitting apparatus **600**, the second semiconductor layers **36**, the tunnel junction layers **37**, and the third semiconductor layers **38** form the columnar sections **30**. The in-plane-direction average refractive index of the portion shifted from the light emitting layers **34** toward the third semiconductor layers **38** in the laminated structure **20** can therefore be lowered as compared, for example, with the

case where the third semiconductor layers **38** do not form the columnar sections **30**. Leakage of the light produced in the light emitting layers **34** toward the third semiconductor layers **38** can therefore be reduced in the light emitting apparatus **600**.

The light emitting apparatus **600** allows reduction in the loss of the light propagating between the columnar sections **30**, as the light emitting apparatus **100** does.

### 6.2. Method for Manufacturing Light Emitting Apparatus

In a method for manufacturing the light emitting apparatus **600**, to epitaxially grow the second semiconductor layers **36**, the tunnel junction layers **37**, and the third semiconductor layers **38**, the epitaxial growth is performed under conditions that allow the layers **36**, **37**, and **38** to grow in the lamination direction. The second electrode **70** is formed on the columnar sections **30**. The second electrode **70** is formed, for example, in vacuum evaporation. The other steps are the same as those of the method for manufacturing the light emitting apparatus **100** described above.

## 7. Seventh Embodiment

A projector according to a seventh embodiment will next be described with reference to the drawings. FIG. **11** diagrammatically shows a projector **900** according to the seventh embodiment.

The projector **900** includes, for example, the light emitting apparatus **100** as a light source.

The projector **900** includes an enclosure that is not shown and a red light source **100**R, a green light source **100**G, and a blue light source **100**B, which are provided in the enclosure and emit red light, green light, and blue light, respectively. In FIG. **11**, the red light source **100**R, the green light source **100**G, and the blue light source **100**B are simplified for convenience.

The projector **900** further includes a first optical element **902**R, a second optical element **902**G, a third optical element **902**B, a first light modulator **904**R, a second light modulator **904**G, a third light modulator **904**B, and a projection apparatus **908**, which are provided in the enclosure. The first light modulator **904**R, the second light modulator **904**G, and the third light modulator **904**B are, for example, each a transmissive liquid crystal light valve. The projection apparatus **908** is, for example, a projection lens.

Light outputted from the red light source **100**R enters the first optical element **902**R. The light outputted from the red light source **100**R is collected by the first optical element **902**R. The first optical element **902**R may have another function in addition to the light collection function. The same holds true for the second optical element **902**G and the third optical element **902**B, which will be described later.

The light collected by the first optical element **902**R is incident on the first light modulator **904**R. The first light modulator **904**R modulates the light incident thereon in accordance with image information. The projection apparatus **908** then enlarges an image formed by the first light modulator **904**R and projects the enlarged image on a screen **910**.

Light outputted from the green light source **100**G enters the second optical element **902**G. The light outputted from the green light source **100**G is collected by the second optical element **902**G.

The light collected by the second optical element **902**G is incident on the second light modulator **904**G. The second light modulator **904**G modulates the light incident thereon in accordance with image information. The projection apparatus **908** then enlarges an image formed by the second light modulator **904**G and projects the enlarged image on the screen **910**.

Light outputted from the blue light source **100**B enters the third optical element **902**B. The light outputted from the blue light source **100**B is collected by the third optical element **902**B.

The light collected by the third optical element **902**B is incident on the third light modulator **904**B. The third light modulator **904**B modulates the light incident thereon in accordance with image information. The projection apparatus **908** then enlarges an image formed by the third light modulator **904**B and projects the enlarged image on the screen **910**.

The projector **900** can include a cross dichroic prism **906**, which combines the light fluxes outputted from the first light modulator **904**R, the second light modulator **904**G, and the third light modulator **904**B with one another and guides the combined light to the projection apparatus **908**.

The three color light fluxes modulated by the first light modulator **904**R, the second light modulator **904**G, the third light modulator **904**B enter the cross dichroic prism **906**. The cross dichroic prism **906** is formed by bonding four right-angle prisms to each other, and a dielectric multilayer film that reflects the red light flux and a dielectric multilayer film that reflects the blue light flux are disposed on the inner surfaces of the combined prisms. The dielectric multilayer films combine the three color light fluxes with one another to form light representing a color image. The combined light is then projected by the projection apparatus **908** on the screen **910**, whereby an enlarged image is displayed.

The case where the projector **900** includes the light emitting apparatus **100** as a light source has been described above, and the projector **900** may include any of the light emitting apparatuses **200**, **300**, **400**, **500**, and **600** as the light source.

The red light source **100**R, the green light source **100**G, and the blue light source **100**B may differ from one another in terms of the film thickness and impurity concentration of the tunnel junction layer **37**.

In the tunnel junction layer **37**, a decrease in film thickness causes a decrease in light absorption but an increase in electrical resistance. In the tunnel junction layer **37**, a decrease in impurity concentration causes a decrease in light absorption but an increase in electrical resistance.

The amount of light absorbed by the tunnel junction layer **37** decreases as the wavelength of the light increases. Therefore, in a light source that oscillates at a long wavelength, the film thickness and the impurity concentration of the tunnel junction layer **37** can be greater but the electrical resistance thereof can be smaller than in a light source that oscillates at a short wavelength. For example, let $T_R$ and $N_R$ be the film thickness and the impurity concentration of the tunnel junction layer **37** in the red light source **100**R, $T_G$ and $N_G$ be the film thickness and the impurity concentration of the tunnel junction layer **37** in the green light source **100**G, and $T_B$ and $N_B$ be the film thickness and the impurity concentration of the tunnel junction layer **37** in the blue light source **100**B, and $T_R>T_G>T_B$ and $N_R>N_G>N_B$ may be satisfied.

The red light source **100**R, the green light source **100**G, and the blue light source **100**B may instead each directly form video images without use of the first light modulator **904**R, the second light modulator **904**G, or the third light modulator **904**B by controlling the light emitting appara-

tuses **100** as the pixels of the video images in accordance with the image information. The projection apparatus **908** may then enlarge and project the video images formed by the red light source **100**R, the green light source **100**G, and the blue light source **100**B on the screen **910**.

In the example described above, transmissive liquid crystal valves are used as the light modulators, and light valves based on any other technology other than the liquid crystal technology or reflective light valves may be used. Examples of such light valves may include reflective liquid crystal light valves and digital micromirror devices. The configuration of the projection apparatus is changed as appropriate in accordance with the type of the light valves used therein.

The present disclosure is also applicable to a light source apparatus of a scanning-type image display apparatus including a light source and a scanner that is an image formation apparatus that displays an image having a desired size on a display surface by scanning the screen with the light from the light source.

The light emitting apparatus according to any of the embodiments described above can be used in another application in addition to a projector. Examples of the application other than a projector may include an indoor or outdoor illuminator, a backlight of a display, a laser printer, a scanner, an in-vehicle light, a sensing instrument using light, and a light source of a communication instrument.

The embodiments and variations described above are presented by way of example, and the present disclosure is not limited thereto. For example, the embodiments and variations can be combined with each other as appropriate.

Further, for example, in the embodiments and variations described above, the first semiconductor layers **32**, the light emitting layers **34**, the second semiconductor layer **36**, the tunnel junction layer **37**, and the third semiconductor layer **38**, are arranged in the presented order from the side facing the substrate **10** in the laminated structure **20** provided on the substrate **10**, but not necessarily, and the third semiconductor layer **38**, the tunnel junction layer **37**, the second semiconductor layer **36**, the light emitting layers **34**, and the first semiconductor layers **32** may be arranged in the presented order from the side facing the substrate **10**.

The present disclosure encompasses substantially the same configuration as the configuration described in any of the embodiments, for example, a configuration having the same function, using the same method, and providing the same result or a configuration having the same purpose and providing the same effect. Further, the present disclosure encompasses a configuration in which an inessential portion of the configuration described in any of the embodiments is replaced. Moreover, the present disclosure encompasses a configuration that provides the same effects and advantages as those provided by the configuration described in any of the embodiments or a configuration that can achieve the same purpose as that achieved by the configuration described in any of the embodiments. Further, the present disclosure encompasses a configuration in which a known technology is added to the configuration described in any of the embodiments.

The following contents are derived from the embodiments and variations described above.

An aspect of the light emitting apparatus includes an electrode and a laminated structure. The laminated structure includes an n-type first semiconductor layer, a light emitting layer, a p-type second semiconductor layer, a tunnel junction layer, and an n-type third semiconductor layer. The electrode is electrically connected to the first semiconductor layer. The first semiconductor layer, the light emitting layer, the second semiconductor layer, the tunnel junction layer, and the third semiconductor layer are arranged in the presented order. The light emitting layer and the first semiconductor layer form a columnar section.

In the light emitting apparatus described above, the p-type second semiconductor layer is joined in the form of a tunnel junction to the n-type third semiconductor layer via the tunnel junction layer, whereby the n-type third semiconductor layer can inject current into the p-type second semiconductor layer via the tunnel junction layer. The third semiconductor layer can therefore be used as an electrode for injecting current into the light emitting layer. Since the n-type third semiconductor layer has an extremely small light absorption coefficient, whereby loss of the light propagating between the columnar sections can be reduced as compared, for example, with the case where an electrode made of ITO is used.

In the aspect of the light emitting apparatus, at least part of the second semiconductor layer may form the columnar section.

In the aspect of the light emitting apparatus, the second semiconductor layer and the tunnel junction layer may form the columnar section.

In the light emitting apparatus described above, in which the tunnel junction layer forms the columnar section, the tunnel junction layer can be made of a high-quality crystal having a reduced amount of crystal defects, whereby deterioration of the characteristics of the tunnel junction layer due to introduction of crystal deflects can be reduced.

In the aspect of the light emitting apparatus, the second semiconductor layer may have a c surface and a facet surface, the tunnel junction layer has a c surface area provided on the c surface and a facet surface area provided on the facet surface, and the impurity concentration of the c surface area may be higher than the impurity concentration of the facet surface area.

In the light emitting apparatus described above, a current narrowing structure that selectively injects current from the c surface area can be formed in the tunnel junction layer.

In the aspect of the light emitting apparatus, the second semiconductor layer, the tunnel junction layer, and at least part of the third semiconductor layer may form the columnar section.

In the light emitting apparatus described above, the in-plane-direction average refractive index of the portion shifted from the light emitting layers toward the third semiconductor layers in the laminated structure can therefore be lowered as compared, for example, with a case where the third semiconductor layers not form the columnar section.

In the aspect of the light emitting apparatus, the tunnel junction layer may join the second semiconductor layer in the form of a tunnel junction to the third semiconductor layer.

In the light emitting apparatus described above, the n-type third semiconductor layer can inject current into the p-type second semiconductor layer via the tunnel junction layer.

An aspect of a projector has the aspect of the light emitting apparatus.

What is claimed is:

**1**. A light emitting apparatus comprising:
an electrode; and
a laminated structure,
wherein the laminated structure includes:
an n-type first semiconductor layer;
a light emitting layer;
a p-type second semiconductor layer;

a tunnel junction layer; and
an n-type third semiconductor layer,
the electrode is electrically connected to the first semiconductor layer,
the first semiconductor layer, the light emitting layer, the second semiconductor layer, the tunnel junction layer, and the third semiconductor layer are arranged in a presented order,
the first semiconductor layer, the light emitting layer, the second semiconductor layer, and the tunnel junction layer form a columnar section,
the second semiconductor layer has a c surface and a facet surface,
the tunnel junction layer has,
a c surface area provided on the c surface, and
a facet surface area provided on the facet surface, and
an impurity concentration of the c surface area is higher than an impurity concentration of the facet surface area.

**2**. The light emitting apparatus according to claim **1**,
wherein the columnar section further includes at least part of the third semiconductor layer to integrally form the columnar section with the first semiconductor layer, the light emitting layer, the second semiconductor layer, and the tunnel junction layer.

**3**. The light emitting apparatus according to claim **1**,
wherein the tunnel junction layer joins the second semiconductor layer in a form of a tunnel junction to the third semiconductor layer.

**4**. A projector comprising the light emitting apparatus according to claim **1**.

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